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OBSERVED CHANGES IN THE STRUCTURE OF THE
"CRAB" NEBULA (N. G. C. 1952)

BY C. O. LAMPLAND

Variations or fluctuations in brightness and changes in form (and possibly changes of position) of the structure in nebulae have so far been observed with certainty in only three objects, N. G. C. 1555 (Hind's variable nebula in *Taurus*), N. G. C. 2261 (Hubble's variable nebula in *Monoceros*) and N. G. C. 6729 (Schmidt's and Innes' variable nebula in *Corona Australis*). In all these objects the fan- or comet-shaped nebulosity is associated with prominent variable stars situated at the apex: *T Tauri*, *R Monocerotis* and *R Coronae Australis*. Changes in the structure of the Crab nebula, *which belongs to an entirely different class than the nebulae just mentioned*, was definitely made out at this Observatory only a short time ago. The announcement of discovery was telegraphed to the Harvard College Observatory March 7th. But a series of photographs of it has been in the making for a number of years and the negatives have been examined from time to time during this interval. In giving an account of the discovery of these changes in the nebula the writer wishes to explain the introduction of digressions that may not appear to bear directly on the subject. The other observational work mentioned hereafter thruout the paper is, however, rather closely related to that on the Crab nebula, for it is only one of the many objects which have been examined repeatedly for the purpose of detecting possible changes, for a period extending over many years. The observed changes in the Crab nebula were established wholly on material obtained with the 40-inch Lowell reflector. The published reproductions of photographs of the nebula are unsuitable for delicate observations of this kind, as the structure is partially obscured or obliterated, or of such exaggerated contrasts in parts that trustworthy intercomparisons would be out of the question. I might mention here that all the photographs of nebulae of the series intended for accurate examinations to ascertain if changes may have occurred were exposed to show as well as possible the detail in the brighter parts. In these observations I have assumed to begin with that these brighter parts of the nebulae would probably be most likely to undergo changes, and exposures suitable to show structure to the best advantage in these regions have been made. In the case of the Crab nebula observations were

begun in 1913 and have been continued from time to time since then. Particular pains have been taken to duplicate the photographs as accurately as possible. The same brand of photographic plates has been used thruout with developer of the same ingredients and proportions and with temperature and time of development always the same (tank development). These details are stated because it so frequently happens in showing images of the very active variable nebula N. G. C. 2261 that we are asked some such question as this: May not these differences be due to effects caused by development not being the same in all cases, or to some other photographic effects? Fortunately, with the large number of excellent images we have of this nebula, taken at frequent intervals—many of them on successive nights—it is an easy matter fully to answer these questions. There are other factors that are more difficult to control in obtaining the same effective exposures as regards density and definition than the development, as for example steadiness of seeing and the transparency. In the series of photographs of nebulae made for inter-comparisons the examinations of the negatives with the Blink-comparator are generally made as soon as the successive plates are taken. Until recently the slight differences in the Crab nebula noted in the pairs examined have been attributed largely to the effects of seeing or minute variations of a photographic nature unavoidable in negatives—but, always keeping in mind that the variations might be real. This reserve has probably been unconsciously acquired in the course of the work, as so many photographs of different nebulae have been examined without success during the past years that I had nearly arrived at the conclusion that it was unprofitable to pursue much longer the program of observations that had been followed. Negative evidence may have some value as far as it goes but as a rule it is not very stimulating to the investigator. As by-products of the work a considerable number of variables and faint stars with motion have been discovered, and there are prospects, but very uncertain ones, that suspected changes in other nebulae may turn out to be real. But to return to the principal topic of the subject in hand.

In comparing one of the recent negatives of the Crab nebula with several negatives of earlier years the differences in some parts were so definite and marked that changes in the structure of the nebula seemed to be highly probable. More minute and extensive

examinations fully confirmed the first impressions. Some of the contours of the nebular masses on the last plate appeared so definite in two localities that the presence of spurious deposit or anomalous effects of contrast were suspected. Exposures were then made on several successive nights in order to settle the matter beyond question. Fortunately observing conditions were favorable so that the observations could be carried out immediately. These later plates checked perfectly with the one in question. In all seventeen negatives were available in the final examinations. Separate pairs of negatives of different years were carefully examined with the result that the differences noted could only be attributed to real changes in the structure of the nebula. Compared with the very active variable nebulae N. G. C. 2261 and 6729 in which the changes in the detail are often very rapid and striking, the Crab nebula must be considered a much more difficult object, but the differences in the photographs of 1913 and 1921—and other pairs such as 1915 and 1916 with 1921—are very evident in the comparator. Without the use of this instrument it is doubtful if the changes would have been detected in nebulous detail of this character. The great advantage of the Blink-comparator is the simultaneous view, practically, of both plates under examination. If the photographs are well matched as to intensity and definition minute differences betray their presence by disturbance in a field placid for parts that are constant or unchanged.

The experience gained in the extensive series of observations carried on during the last five years on the variable nebulae N. G. C. 2261 and N. G. C. 6729 was helpful in the present work. Hubble's variable nebula, especially, has been observed as systematically as possible. In this way the progressive changes in the detail can be studied minutely and slight variations in the structure, as development takes place, can be checked—a matter of some importance in training the judgment of the observer in observations of this kind.

In form and in the character of its detail the Crab nebula may be said to stand in a class by itself. It is an object of complex structure, roughly an ovate nebulous mass, having at first sight the appearance of a coarsely and crudely woven fabric shot thru with loose-spun, thread-like filaments, giving it a peculiar frayed or raveled aspect along its border. On closer inspection the protruding filaments are found not to be so conspicuous and apparently

not so numerous in the much brighter interior in which the structure is very intricate, evidently resulting from the integrated effects of ramifying fibrous detail with the numerous component small, more or less diffuse, nebulous masses, all projected on a fainter nebulous background.

I shall not attempt to give here a full account of the rather complex changes in the nebula as they appear in the comparator on photographs separated by intervals of several years.

The longer axis of the nebula lies approximately in P. A. 120° and the dimensions of greatest width and length, to the ends of the outlying parts of the filaments, are roughly $4' \times 5\frac{1}{2}'$. For convenience of reference the north component of the double star near the center of the nebula will be taken as origin and the sequence of the quadrants will be in the order of reckoning position angles. The components of this double star are of about the same brightness, and the position angle and distance of the pair about 200° and $5''$. The magnitudes may be as faint as 16.5 but this estimate is only approximate as the stars are surrounded by nebulous matter and are projected on a nebulous ground.

The most marked changes in the nebula have taken place in the area mostly included in the fourth quadrant (P. A. 270° - 360° , relative to the double star previously mentioned), within a radius less than two minutes of arc, in the nearly central, prominent and brilliant, region about $45''$ wide extending from the double star near the center toward the west and north nearly in the direction of the longer axis of the nebula (P. A. about 315°). In this region are found several conspicuous differences between the 1921 photographs and those of earlier years. On the 1921 negatives there is an elongated mass ($48'' \times 15''$, its longer axis with P. A. about 50°) in P. A. 320° and distance about $45''$, which stands out prominently in a region where the nebulosity was somewhat diffuse in 1916 and earlier years. In parts the contour of this mass is well defined on recent photographs compared with the earlier ones mentioned. In fact some of the details in this region are so definite and the appearance so much changed that the differences were at first suspected not to be real. But photographs taken on several nights following this negative are in perfect accord with it. These last negatives compared with several of earlier years left no doubt that the differences in the structure were real. Conspicuous changes have also occurred between this mass and the origin but

the area involved is considerably smaller. Well-marked differences also stand out near the origin (the central double star) in P. A. 290°, distance 10", in the form of a small elongated condensation (P. A. 30° of the longer axis) quite narrow and of considerably increased brightness on the last negatives. This small condensation has developed from a small and more diffuse mass of earlier years, giving the impression that its inner edge has receded slightly from the double star and has been gathered into the narrower, brighter and more sharply defined mass on the recent negatives. Another region of interest is in the vicinity of the small star, a little fainter than the components of the central double, in P. A. 330° and distance 70". On the later photographs a partially cleared space, roughly triangular 15" x 20", appears just south of this star. On photographs of 1916 and earlier this space is filled with nebulosity which has diminished in brightness or partly cleared away in recent years. Several less conspicuous changes are evident in the region about this star. The image of the nebula in 1918 shows a resemblance to the present forms and configurations of the structure. It should hardly be necessary to remark that the differences noted cannot be attributed to seeing, as it has been possible for some of the pairs to select the negatives so that the detail in the 1921 plate is perceptibly inferior in definition, due to seeing, than the earlier plate.

In the first quadrant there are very noticeable changes in some of the brighter nebular matter which is a continuation of the large bright elongated area in the fourth quadrant mentioned at the beginning of the preceding paragraph. Changes in several very tenuous filaments, just perceptible in the nebulous background, are also shown.

Small variations in the structure are perceptible in many other parts of the nebula. On the other hand much of the detail is apparently constant in brightness and form, and if changes are in progress a longer time interval will be necessary for detecting them. Small nuclei or stars in two or three places may be variable. Slight displacements and differences in some of the filaments may also be mentioned.

It should be recalled that the spectrum of this nebula is unique. It contains emission lines of the most extraordinary character as was announced early in 1915 by Dr. V. M. Slipher from his spectrograms, of which he has several since 1913.

An important part of the work—the interpretation of the results—still remains to be done. It is to be expected that more observational material will be required. Some of the changes such as the apparent displacement of the filaments or parts of them may be due to actual motion. Then again the apparent displacements of nebular masses may result wholly or in part from local brightening or fading of the matter in these areas. That some regions of the nebula are of variable brightness is shown by the present series of photographs. Criteria for testing this statement are furnished by the nebula itself in various regions where details of different degrees of brightness show no variability in the light.

Lowell Observatory, March 21, 1921.